Auditory Hazard Units as an Index of Risk from Intense Sounds

G. Richard Price

US Army Research Laboratory

and

AHAnalysis

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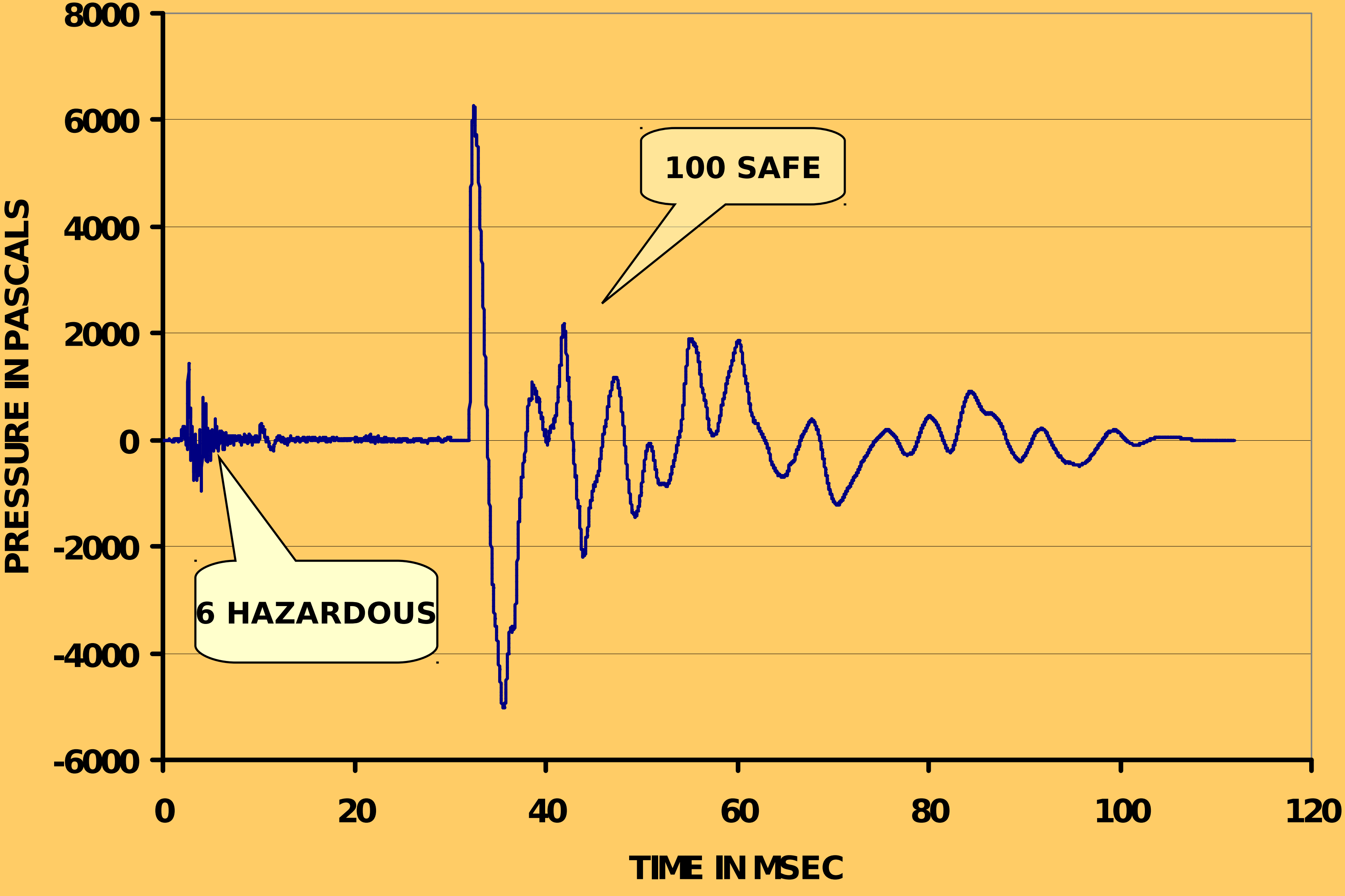
The Impulse Noise Problem

- A long history
- Baffling data with traditional measures, e.g.
  - If A-weighted energy is used:
    - 2000 - 3000 J/M^2 measured under a muff found acceptable for cannon impulses.
    - Implies that 2000+ rounds unprotected exposure from a rifle would be safe
    - In fact, fewer than 10 rounds are hazardous

Consider Peak Pressure and Duration



Our approach to the problem

- Try to understand the ear’s behavior at high level’s of simulation,
- Then devise a measure that was critically related.
- The ear’s response is complex
  - Several non-linearities
  - Simple graphic approach won’t work.
- A mathematical model of the ear created to deal with the complexity – the Auditory Hazard Assessment Algorithm for Human (AHAAH)
- A new unit of hazard produced:

The Auditory Hazard Unit (AHU)

- Defined within cochlea (site of damage) as:
  - Peak upward deflection of the basilar membrane
  - In microns
  - Squared
  - Summed at a location

AHU = Sum (of peaks in microns^2)

- Is an output of AHAAH

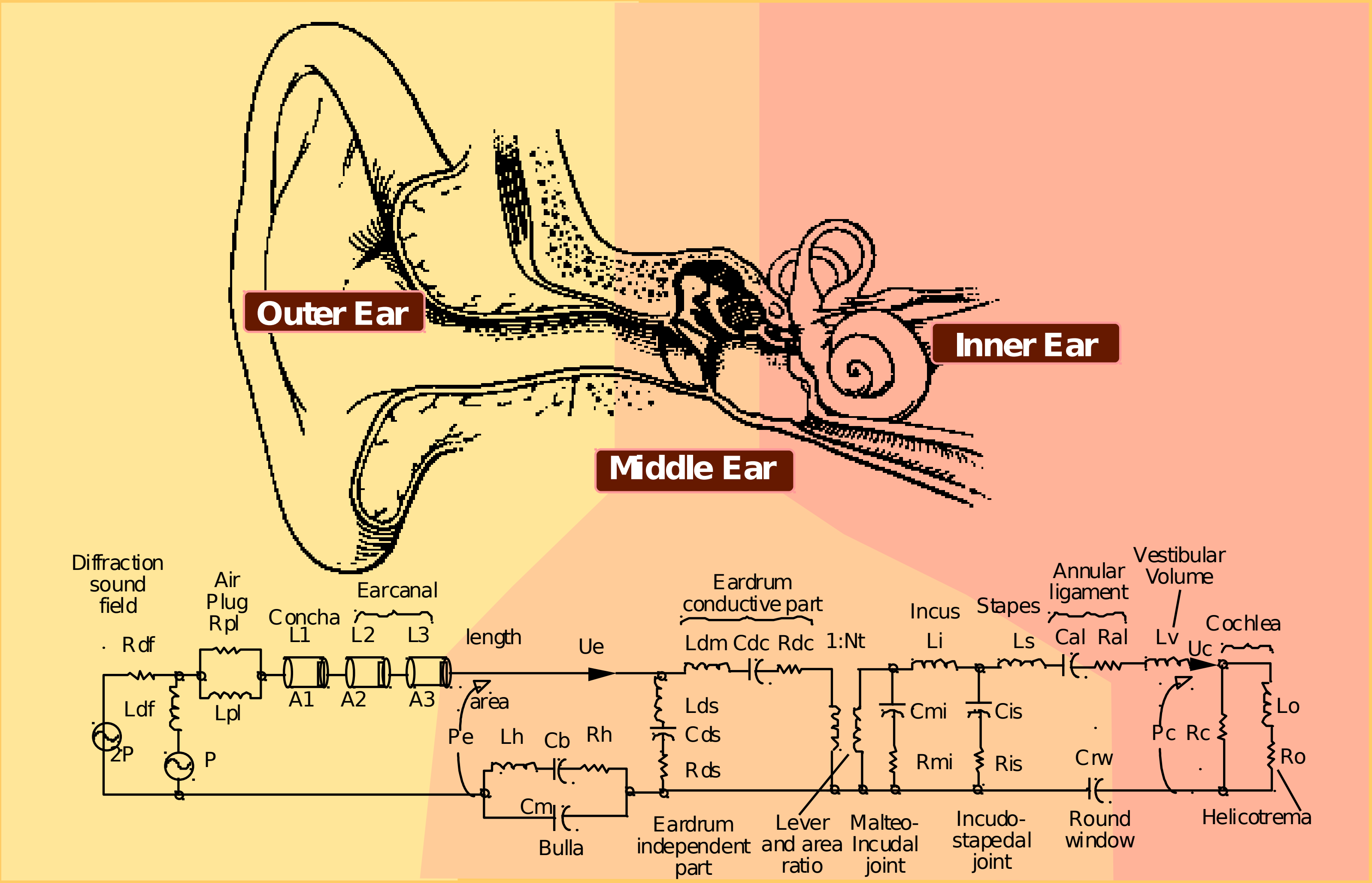
Insights Embodied in AHAAH

- Primary site of damage is the organ of Corti.
- Loss mechanism is mechanical at high SPLs and becomes linear in time.
- External and middle ears shape the flow of energy:
  - A band-pass filter.
  - Middle ear muscles, when contracting, attenuate by stiffening the middle ear.

Basic Research Insights Embodied in AHAAH (continued)

  - Annular ligament limits middle ear displacements - strongly peak clips at very high pressures.
- Mammalian ears are similar; hence fundamental loss processes will be as well.
- <u>Accurate</u> prediction is the goal:
  - Under-prediction results in hearing loss
  - Over-prediction results in unnecessary restrictions and ineffective systems

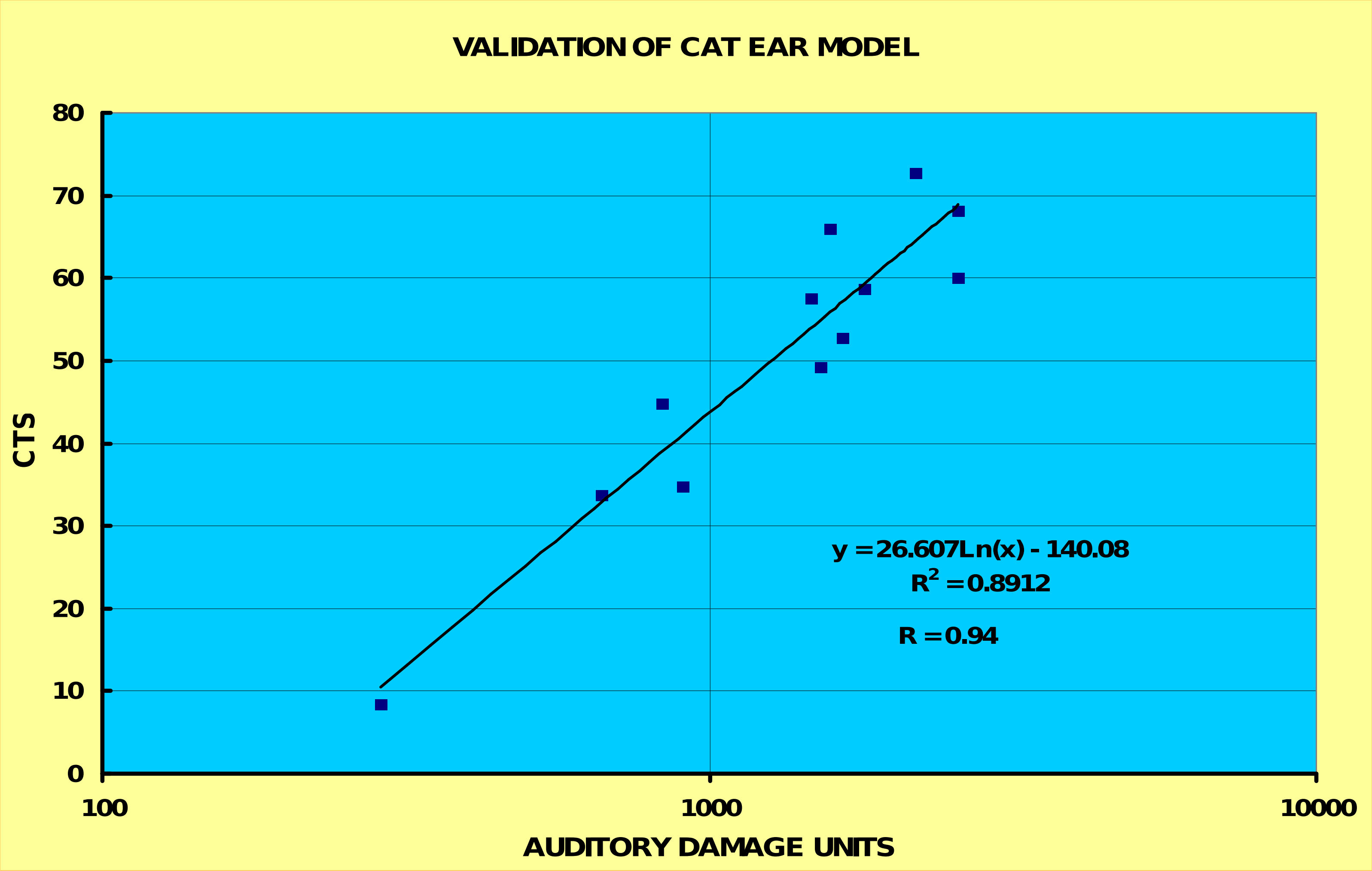
AHAA Developed



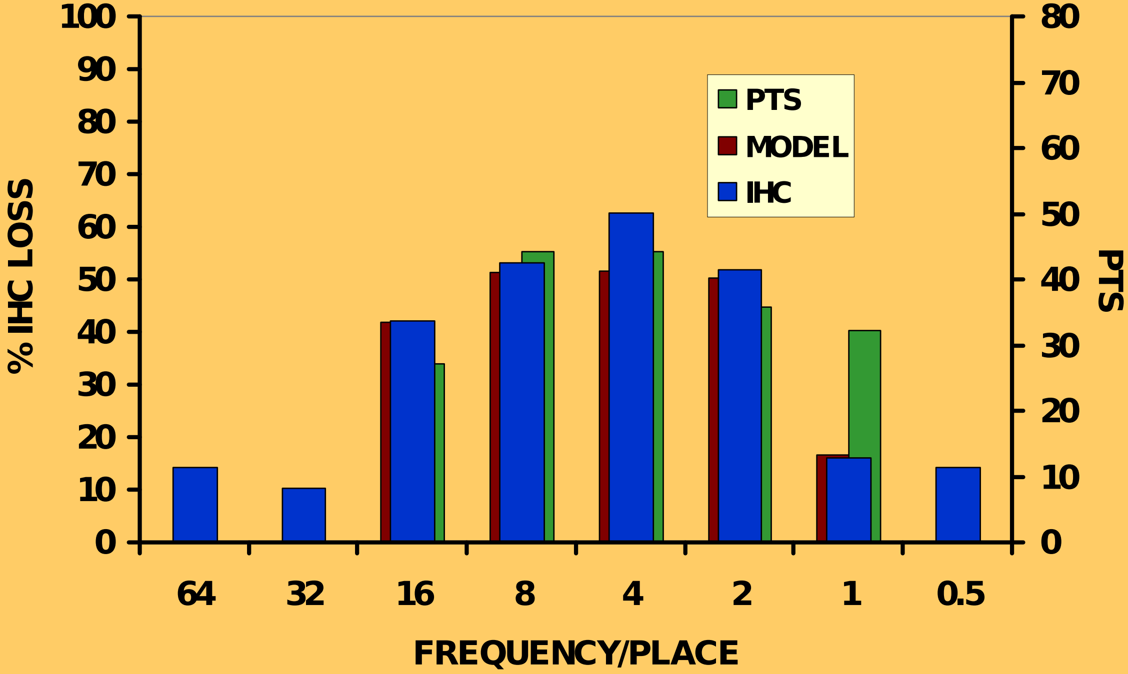
Creation of AHAA

- Created first for the cat ear – allowed real ears to be tested with damaging stimulation
- Electrophysiological measures of hearing used
- Wide range of conditions tested
  - Primer impulses
  - M-16 rifle impulses
  - Airbags
  - SPLs from 135 to 172 dB peak
  - 1 to 50 impulses
- Predictions of AHAA compared with effects

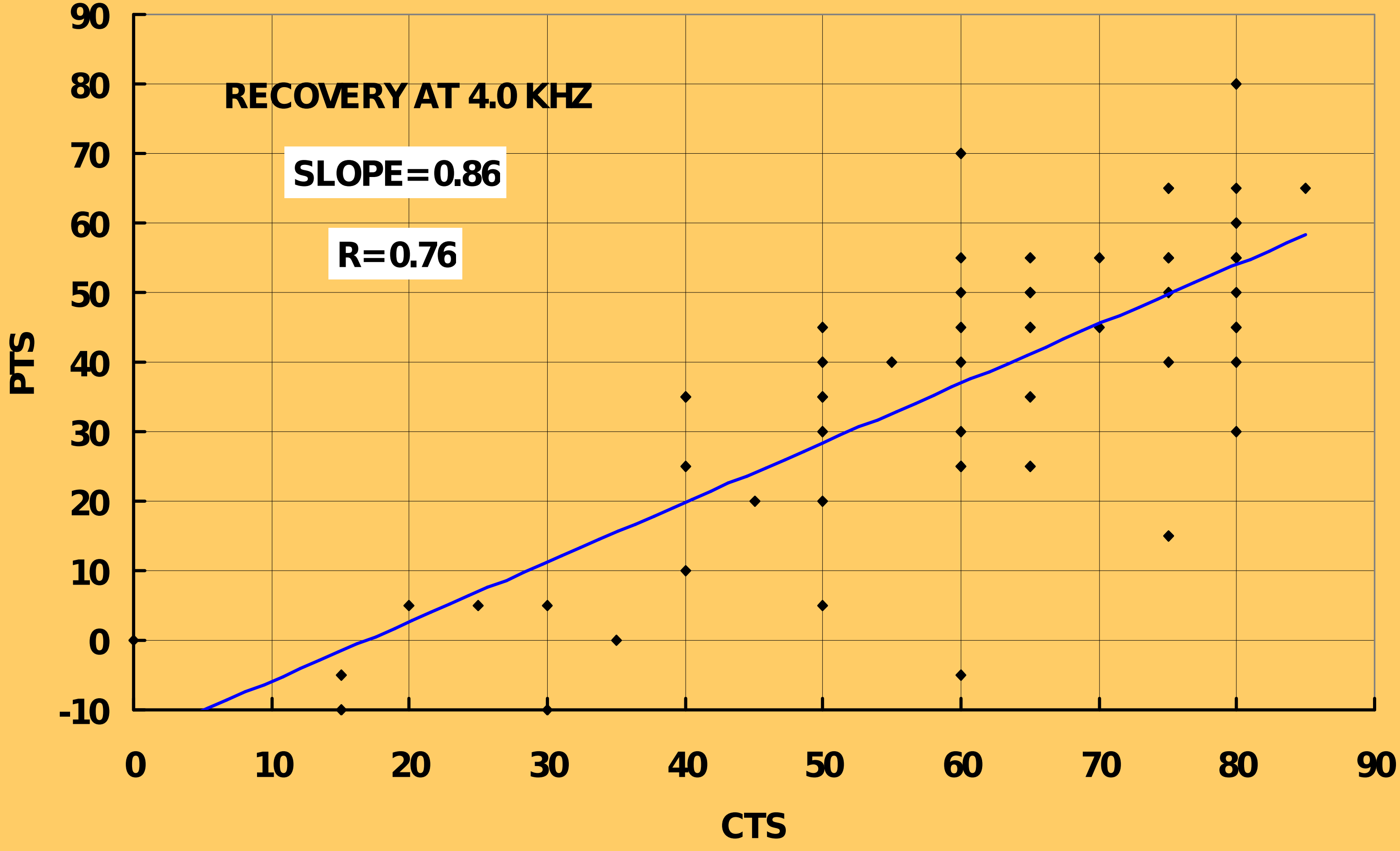
Prediction of Threshold Shift



Correlation with hair cell loss



CTS-PTS Relationship



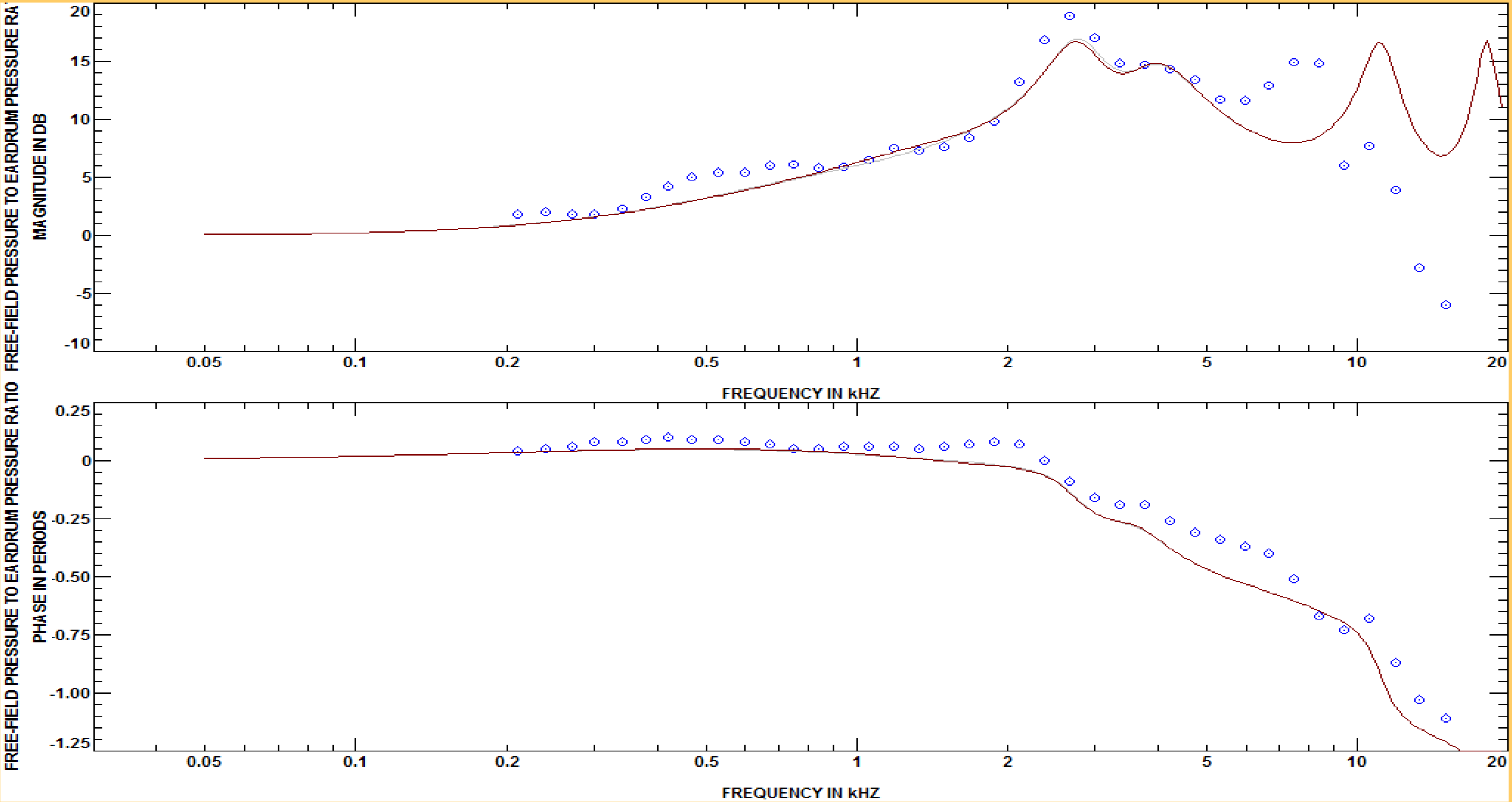
For Cat Model:

- Predicts:
  - CTS
  - PTS
  - Hair cell loss
- For wide range of stimuli
- Model ready for transformation into human form

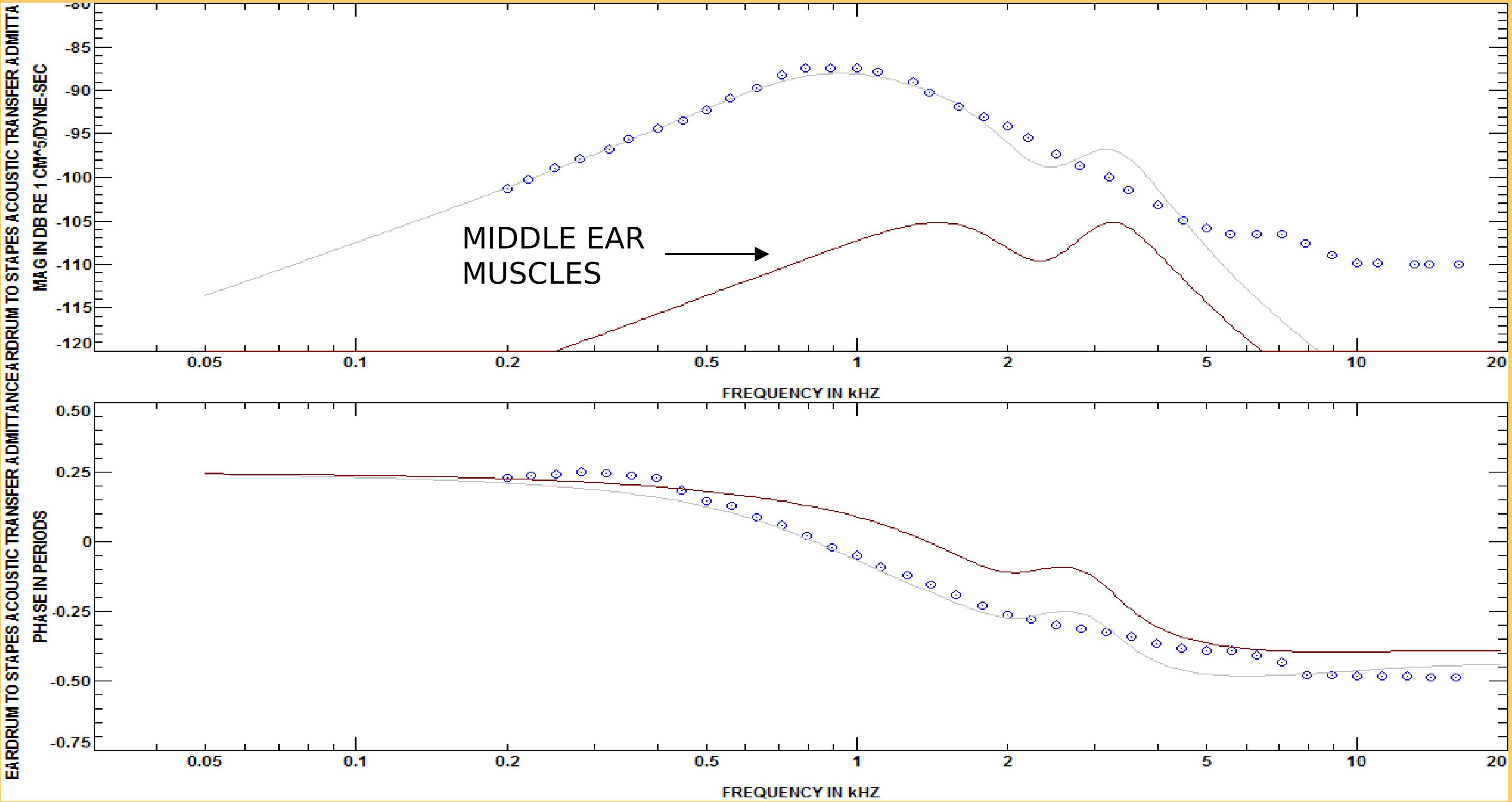
Creation of the Human Version

- Variables changed to human values
- Adjusted to get conductive path correct
- Stapes to basilar membrane transfer set to be similar to cat in mid-range of sensitivity
- Note: no hearing loss data used at this point (1997)
- Expectation:
  - Try to predict hearing loss data
  - Adjust as necessary
- In fact, no adjustment has been necessary

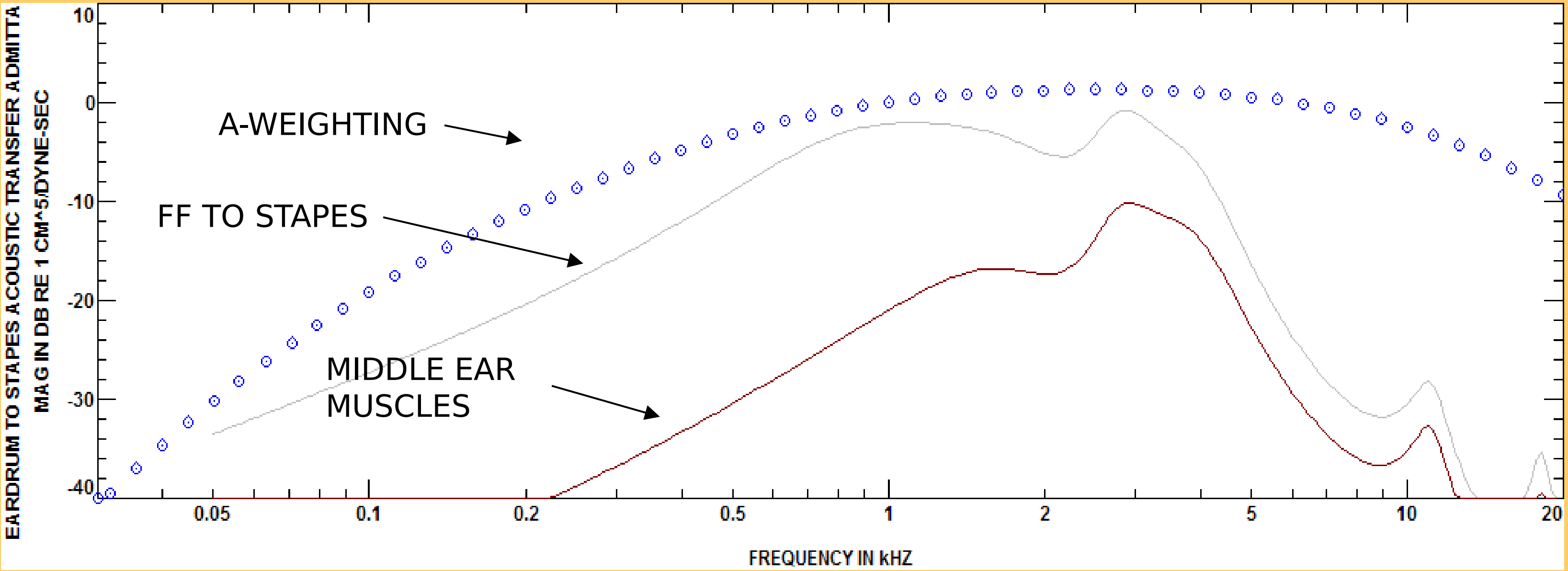
Transfer function – FF to Ear Drum



Transfer function: ED to Stapes



FF to Stapes, A-Weighting



But does AHAAH predict hazard?

- Compare AHUs from waveforms from human exposures with resulting changes in hearing
- Data sets available:
  - Albuquerque data
  - Small arms studies
  - Spark gap discharges
  - 120 mm mortar
  - Some clinical data

The Albuquerque Data

- Large caliber fire simulated with explosive charges
- 3 types of free field impulse
  - At 7 levels (3 dB steps)
  - For 6,12, 25, 50 or 100 impulses
  - 178 dB to 194dB peak
- A reverberant impulse (at 7 levels, 1,2,3 rds)
- 2 HPDs
- In all, 53 conditions with 60 Ss per condition

Hazard is predicted when:

- For AHAAH: >500 AHUs (sum during exposure)
- For A-weighted energy: >8.7 J/m^2 (total during exposure)
- For MIL-STD 1474: Peak pressure/duration exceeds limits on chart

How do we define “success” in a prediction ?

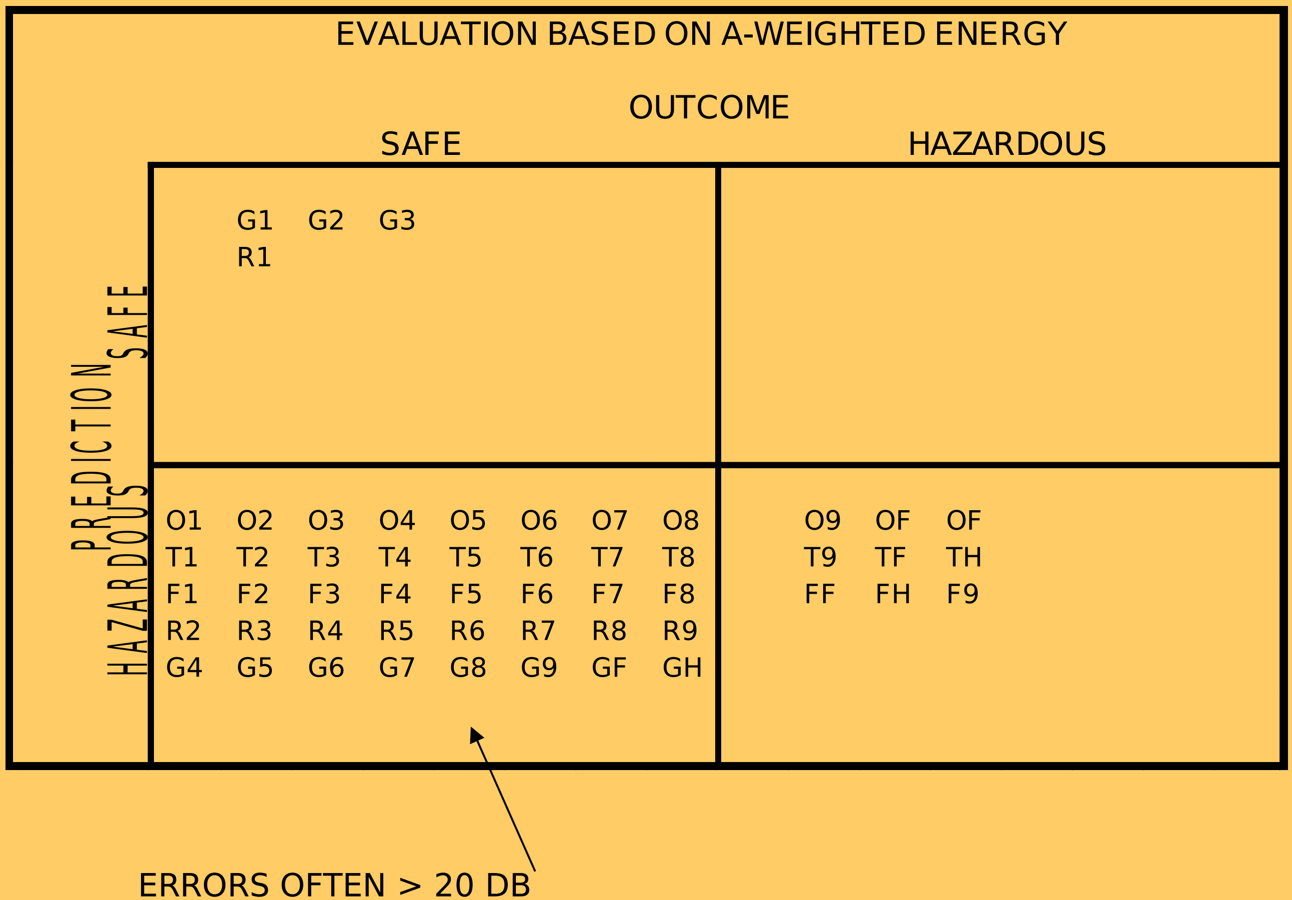
- Hazard for an ear = >25dB TS at any frequency
- To be 95% sure that 95%ile case has been reached, for n= 60, must have 6 or more “failures”, i.e. >5 failures = hazardous condition
- Or, if failure is predicted, can’t say it was not hazardous if a least one failure occurs.
- For 2 to 5 cases, just can’t be 95% certain.
- Rule(s) applied to predictions by MIL-Std 1474, A-weighted energy and AHAAH.

Evaluation Diagram

		OUTCOME	
		SAFE	HAZARDOUS
PREDICTION	SAFE	CORRECT RATING	UNDER-ESTIMATE AUDITORY CASUALTIES POORER COMMO MISSION ENDANGERED
	HAZARDOUS	OVER-ESTIMATE LESS EFFECTIVE WEAPONS MISSION ENDANGERED EXCESS CASUALTIES	CORRECT RATING

EVALUATION BY MIL STD-1474

		OUTCOME	
		SAFE	HAZARDOUS
PREDICTION	SAFE	01 T1 T2 F1 F2 F3 G1 G2 G3 R1 R2	
	HAZARDOUS	O2 O3 O4 O5 O5 O7 O8 T3 T4 T5 T6 T7 T8 F4 F5 F6 F7 F8 F9 G4 G5 G6 G7 G8 G9 GF GH R3 R4 R5 R6 R7 R8	O9 OF OH T9 TF TH FF FH R9


EVALUATION BASED ON A-WEIGHTED ENERGY
OUTCOME
SAFE
HAZARDOUS
PREDICTION
SAFE
HAZARDOUS
G1 G2 G3
R1
O1 O2 O3 O4 O5 O6 O7 O8
T1 T2 T3 T4 T5 T6 T7 T8
F1 F2 F3 F4 F5 F6 F7 F8
R2 R3 R4 R5 R6 R7 R8 R9
G4 G5 G6 G7 G8 G9 GF GH
O9 OF OF
T9 TF TH
FF FH F9
ERRORS OFTEN > 20 DB

EVALUATION BY AHAAH

		OUTCOME	
		SAFE	HAZARDOUS
PREDICTION	SAFE	O1 O2 O3 O4 O5 O6 O7 O8 T1 T2 T3 T4 T5 T6 T7 T8 F1 F2 F3 F4 F5 F6 F7 F8 G1 G2 G3 G4 G5 G6 G7 G8 G9 R1 R2 R3 R4 R5 R6 R7 R8	
	HAZARDOUS	GF GH R9	O9 OF OH T9 TF TH F9 FF FH

Exposure to other impulses

- Need good waveform for AHAAH analysis or A-weighted energy measure
- Data reported vary with study – AHAAH can calculate equivalent data for comparison
- Keep criterion of 25 dB threshold shift at any frequency as hazardous.

Summary of AHAAH Predictions

- 7.62mm, 50rds at 155dB - correct
- 7.62mm, 25rds at 155dB - correct
- 7.62mm, 25rds at 158dB - correct
- FNC 6 rounds at 156dB - correct
- FNC 5 rounds at 156dB - correct
- G3 5 rounds at 159dB- correct
- LAW 1 round - correct on 5 different exposures
- Spark Gap impulses - correct on 4 predictions
- AT4, 1 round, correct
- 120 mm Mortar, 7 rounds, protected ears, correct

In summary

- AHAAH: 95% accuracy over all
- MIL STD 1474: 38% accuracy (protected ears)
- A-weighted energy: 30% accuracy over all
- AHAAH model works well
  - All types of impulses
  - Protected ears
  - Unprotected ears

Why does AHAAH work so well in comparison to other methods?

- At lower pressures, the normal transmission path dominates and the model reproduces it. (Similar to A-weighting).
- It accounts for middle ear muscle attenuation
- **Most important:** at higher pressures, non-linear middle ear correctly limits energy entering cochlea.
- Given a non-linear middle ear, linear systems, if correct at one pressure/frequency regime, must be wrong elsewhere.

Functional issues: Accounting for hearing protection

- Pressure waveforms measured under protector on a manikin at ear drum position or ear canal entrance can enter AHAAH at the right “place” and are properly evaluated.
- If a manikin is used, angular dependence of hazard is also correctly determined.
- Or effect of HPD can be calculated with digital filter or model – allows ‘de-rating’ to account for fit.

Operational issues – How it works

- Runs on a PC – short analysis time.
- Uses WINDOWS conventions
- Program includes tools for importing, editing, analyzing and printing waveforms.
- Operates on a digitized waveform.
- Outputs hazard in AHUs and
- Makes a movie of the action within the cochlea (allows engineering insight)

“Official” Status of Model

- Peer reviewed at request of U.S. Army Medical Research and Development Command by the American Institute of Biological Sciences

AIBS Peer Review Affirmed:

“ The Panel recommends that free-field pressure traces should be input to the model ---------------- and that personnel be allowed to be exposed to combinations of noise that does not result in more than 500 ADUs per day. The Panel feels that it was satisfactorily demonstrated that this limitation would produce 95/95 protection – that is, there is 95% confidence that 95% of the population will experience temporary threshold shift (TTS) that is less than 25 dB. The Panel feels that the process can be applied to all impulse noise conditions, including those whose pressure-time histories appear to be quite different from the ones collected in the Albuquerque study, and still provide the same protection. Finally, the Panel feels that this criterion will provide adequate protection against unacceptable auditory damage over the soldier’s occupational lifetime, as long as the devices are worn and properly fit.”

“Official” status of model

- Successfully peer reviewed by AIBS
- Used internationally by SAE as basis for evaluation of noise of airbag deployment
- Being proposed to Army’s Surgeon General by USACHPPM as basis for impulse noise hazard rating (first ever!).
- In draft ANSI standard – (legacy of Dan Johnson)
- Used by NOISH, SAIC, DEBAKOM
- Will be available, with documentation, on ARL website

Thank you for your attention!

Any questions?